

RESOLVING SENSORY CONFLICT - THE EFFECT OF
MUSCLE VIBRATION ON POSTURAL STABILITY

Final Report

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ABSTRACT

The otolith-tilt reinterpretation hypothesis (OTTR) proposes that the CNS adapts to weightlessness by reinterpreting all otolith input as linear motion (Parker et al., 1985). This reinterpretation can be considered a strategy which the CNS uses to resolve the conflict between mismatched sensory inputs. While interpreting otolith input exclusively as linear motion is functionally useful in weightlessness it is maladaptive upon return to Earth. Astronauts have reported experiencing illusory sensations during head movement which contributes to postural instability. Disfunctional central or peripheral processes can result in sensory conflicts which, if not resolved, impair motor functioning. The purpose of this study was to assess the effect of muscle vibration in combination with a variety of sensory conflicts on postural equilibrium. The equilibrium of six healthy subjects was tested using the EquiTest sensory test protocol (NeuroCom International, INC.) with and without the confounding influence of triceps sura vibration. The sensory test conditions were randomized within two test blocks (vibration, no vibration). Sixty hz vibration was continuously applied to the triceps sura during the 20 second trials within the vibration test block. The data were analyzed with a 2x3x2 ANOVA with repeated measures with vibration, vision status, and platform status as independent variables. The subject's lowest equilibrium score from each condition was the dependent measure. Student t tests were used to assess the impact of muscle vibration within a sensory test condition. All main effects and an interaction between the presence of vision and platform sway referencing were found to be significant. Overall, a 4.5% decrease in postural stability was observed with vibration. However, equilibrium was only significantly affected in EquiTests conditions 1-4. The trend of the difference scores between conditions with and without vibration suggests that vibration is most destabilizing when the triceps sura is able to change length during postural sway (ie. conditions with a fixed support surface). The impact of sway referencing vision was virtually identical to that of eye closure, providing compelling evidence that sway referencing "nulls out" useful cues about subject sway.

INTRODUCTION

While the phenomena of postflight postural instability has not been systematically investigated, there is anecdotal evidence indicating that postural equilibrium is significantly impaired following spaceflight. For instance, returning astronauts have reported experiencing turning sensations while walking straight, perception of large pitch and rolling head movements during locomotion, and loss of postural stability when rounding corners. These illusory sensations suggest that varied sensory inputs are providing conflicting information during readaptation to the Earth's gravitational field. The inability of the perceptual-motor system to reconcile conflicting sensory inputs leads to postural disorders which will delay an emergency egress from the space shuttle.

During extended orbital flight, neural processes adapt to recalibrate the central nervous system to microgravity. Such neural adaptations result in efficient motor control in microgravity. However, the neural adaptation achieved during spaceflight is inappropriate for a 1-g environment leading to postural instability on return to Earth. The otolith tilt-translation reinterpretation (OTTR) hypothesis has been proposed to explain how the nervous system adapts to the altered vestibular input of spaceflight (Parker et al., 1985). On Earth information from the otolith receptors of the vestibular system is interpreted by the perceptual-motor system as either tilt with respect to gravity or linear motion. Since gravity stimulation is absent in microgravity, interpretation of the otolith input as tilt is meaningless. Therefore, the central nervous system adapts by reinterpreting all otolith input as linear motion. Following return to Earth and before the system readapts to unit gravity, the interpretation of all otolith input as tilt persists, producing illusions of self or environmental motion during head motion. These illusions greatly contribute of postflight postural instability.

The OTTR is a strategy used by the perceptual-motor system to resolve one form of sensory conflict. Specifically, the conflict between inappropriate otolith input and appropriate (for the most part) visual and proprioceptive input. A similar strategy (reinterpretation of a sensory input) may be used to resolve different types of conflict such as the conflict between

inappropriate proprioceptive input and appropriate visual and vestibular inputs.

One method by which to generate sensory conflict is through the use of muscle vibration. Muscle vibration causes rapid, alternating lengthening and shortening of the sensory region of the muscle spindle. Externally imposed rapid length changes in the sensory region distorts spindle output, causing a misperception of muscle length. Misperception of muscle length leads to inaccurate assessment of limb position, resulting in movement disorders including postural instability. Goodwin and his colleagues (Goodwin et al., 1972) were pioneers in the use of muscle vibration. They used a variety of experimental conditions to study the affect of vibration on limb position. Their results consistently indicated that the vibrated muscle was always perceived to be longer than its actual length. The perception of exaggerated length led to muscle contractions designed to shorten the muscle and return it to, what was perceived to be, the desired length. This process resulted in inappropriate limb joint angles to accomplish the intended environmental goal. Since Godwin et al., (1972) initial work, a number of investigators have confirmed their findings (Roll and Vedel, 1982; Rogers et al, 1985; Magnusson and Johansson, 1989; Pyykko, et al., 1991).

Vibration of the triceps surea (gastrocnemius and soleus) in standing subjects leads to backward sway as the muscle contracts in an effort to adjust the muscle to the perceived appropriate length. Contraction of the already appropriate length muscle leads to a new equilibrium point of the body's center of gravity (COG) posterior to the ankle joints. However, the vestibular system accurately perceives the incorrect posterior equilibrium point and attempts are made to properly realign the COG. Thus, the net affect of triceps surea vibration is increased sway relative to quiet standing as the conflicting sensory inputs "battle" each other in an effort to establish the length of the triceps surea. The unresolved conflict between competing sensory inputs during muscle vibration raises the question of the relative effects or "weighting" of unique sensory inputs and whether such weightings are context dependent.

A method by which to address the question of relative weighting of sensory inputs during postural control is to eliminate the input altogether (ex. eye closure) or manipulate the input such that it conflicts with other sensory inputs. A commercially available

postural equilibrium testing system functions to "null out" both proprioceptive inputs from the ankles and/or visual input (EquiTest system, NeuroCom International, INC.). The effect of "nulling out" proprioceptive and/or visual input on a subject's postural stability can be used to infer the extent to which a subject relies upon or "weights" a specific sensory input during standing. The generation of sensory conflicts using the EquiTest system also provides the possibility of determining if specific conflicts are resolved such that the intended goal can be accomplished. For example, visual input may be so heavily weighted during standing that conflicting input resulting from muscle vibration has no negative impact upon postural stability. Conversely, the weighting of the vibration induced proprioceptive input may be such that sway increases despite conflicting visual and vestibular inputs. It is also possible there are contextually dependent interactions of unique sensory inputs. As there are many theoretical possibilities of how a variety of sensory conflicts are resolved, it is important to elucidate how the perceptual-motor system responds to a variety of input combinations known to produce sensory conflict. It may be that common elements exist between the various methods of conflict resolution.

The purpose of the present study was to determine the effect of triceps surae muscle vibration on postural equilibrium during a variety of conflicting sensory inputs and to assess the relative importance of vestibular, visual, and proprioceptive input during standing postural control.

METHODS

Subjects

Six individuals (three females, three males) with no diagnosed central or peripheral nervous system deficits served as volunteer subjects.

Instrumentation

In order to assess the effect of muscle vibration under a variety of conflicting sensory conditions, the EquiTest/postural testing system was used (see Introduction). The posture platform is

comprised of a potentially moving visual surround and two independently movable force plates (one for each foot) which rotate about an axis co-linear with the ankle joint. The potentially movable support surfaces and visual surround were exploited to induce a variety of conflicting sensory inputs. For example, in sensory test condition 4 the support plates were programmed to respond to the subject's anterior-posterior (A-P) sway by exactly following the degree of sway (Figure 1). In this test condition, sway about the ankle joints does not result in a change in ankle joint angle or a stretching of the ankle musculature. Thus, proprioceptive cues normally available to signal postural sway are "nulled out" with the resulting proprioception conflicting with vestibular and visual inputs. Similarly, visual inputs can be "nulled out" and therefore conflict with other sensory input. Sensory test condition 6 involves the "nulling out" of both proprioceptive and visual inputs leaving only the vestibular system to correctly indicate the true upright position with respect to gravity. A postural equilibrium score for each condition is computed by comparing the angular difference between a subject's maximum posterior and anterior COG displacements to the theoretical maximal displacement of 12.5 degrees. The score is then converted to a percentage with 100 indicating perfect stability (no sway) and 0 signaling a fall. Equilibrium scores are provided by the EquiTest system.



















EquiTest™ Conditions		Sensory Analysis	
1.		Normal Vision	
	Fixed Support		Static Muscle Length
2.		Absent Vision	
	Fixed Support		Changing Muscle Length
3.		Sway-Referenced Vision	
	Fixed Support		Changing Muscle Length
4.		Normal Vision	
	Sway-Referenced Support		Static Muscle Length
5.		Absent Vision	
	Sway-Referenced Support		Static Muscle Length
6.		Sway-Referenced Vision	
	Sway-Referenced Support		Static Muscle Length

Figure 1. - Sensory test conditions

Procedures

Preliminary evidence suggested a rapid learning curve is associated with the sensory test protocol. In order to decrease the confounding influence of learning, the subjects were exposed to the six test conditions the day prior to the testing session (Day 1). Equilibrium scores were obtained during this testing session. As in all sensory test conditions, the subjects stepped onto the platform and white noise was applied through a pair of stereo headphones. This procedure is used to mask any auditory cues available to the subject from the testing environment and motion of the visual

surround. A microphone was used to communicate with the subject through the headphones. Prior to testing, the subject was fitted with a safety harness which prevents falls to the support surface.

During the testing session (Day 2), the six sensory conditions were randomly presented within blocks of the six conditions. Each condition (trial) lasted for 20 seconds and each sensory condition was presented three times for a total of 18 trials (1 block). The same procedure was followed during the sensory tests with vibration. Sixty hz vibration was applied to the lower third of the triceps surae muscle by physiotherapy vibrators held in place by Velcro bands. Vibration was applied the entire 20 seconds during sensory test conditions with vibration. Within a testing block, vibration was either always present or never present. The order the subjects received vibration (i.e. vibration in block 1 or block 2) was counterbalanced. Following completion of the first block of sensory tests the subjects rested comfortably in an adjoining room while the next subjects completed a block of tests. The first subject then returned to the laboratory to complete the second test block. This procedure prevented psychological and physiological fatigue. All tests were conducted in the Dynamic Posture Laboratory (Intermetrics, 1290 Hercules) associated with Johnson Space Center's Neuroscience Laboratories.

Statistics

In order to assess the effects of the manipulated sensory variables on postural equilibrium, the data were analyzed with 2x3x2 analysis of variance (ANOVA) repeated measures to obtain a multivariate solution. The individual subject's lowest equilibrium score in each of the conditions was the dependent measure. The first variable was vibration with the two levels being (1) present or (2) absent vibration. The second variable was vision with the three levels being (1) present, (2) absent, and (3) sway referenced. The third variable was platform status (i.e. ankle proprioception) with the two levels being (1) fixed and (2) sway referenced. This design tested whether each variable's influence on postural equilibrium was significant and whether any significant interactions between the variables influenced equilibrium. The effect of each factor was computed by subtracting the treatment mean from the baseline (no treatment) mean. The results of this procedure reflect the negative

impact of manipulating a particular sensory input on the subject's equilibrium. One-tailed Student *t* tests were used to assess the impact of vibration within a sensory condition (ex. condition 1, with and without vibration). In order to further investigate the effects of vibration under a variety of sensory conditions, difference scores were computed by subtracting the mean from a sensory condition with vibration from the mean of that condition without vibration. An alpha level of 0.05 was chosen for all statistical tests.

RESULTS

The results of the ANOVA indicate that all main effects and an interaction between vision and platform sway referencing were significant. Plotting the data revealed an interaction between platform sway referencing and the presence of vision. Table 1 lists the mean effect of each unique sensory variable.

TABLE.1- PERCENTAGES OF EFFECTS OF SENSORY VARIABLES ON POSTURAL EQUILIBRIUM

Sway Referenced Platform	-17.417%
Sway Referenced Vision	-11.875%
Absent Vision	-10.708%
Vibration	-4.472%

Vibration significantly increased postural sway in sensory conditions 1 through 4 but had no significant influence on conditions 5 and 6. There was no evidence of learning with repeated exposure to the sensory test conditions with or without vibration. Table 2 lists the mean difference in equilibrium scores between a particular sensory test condition with and without vibration. The values reflect the negative impact of vibration on the mean equilibrium score.

TABLE 2.- MEAN DIFFERENCE EQUILIBRIUM SCORES

Condition 1	-4.5*
Condition 2	-7.8*
Condition 3	-5.0*
Condition 4	-5.3*
Condition 5	-0.8
Condition 6	-3.8

*significant at .05 level

DISCUSSION

The results of the present experiment confirm that vibration of the triceps sura has a significant negative impact on postural equilibrium. This is consistent with the findings of previous investigators (Roll and Vedel, 1982; Pyykko, et al., 1991). The statistical procedures used to analyze the data resulted in the computation of percentages reflecting the negative effects of specific manipulations of sensory inputs (Table 1). The lack of significant interactions except for the presence of vision and platform sway referencing suggests that the effect of each of the sensory manipulations can be considered independent (except when the platform sway referencing and normal vision are paired) and therefore, additive. For instance, an equilibrium score of 67.403 is predicted with a sensory condition involving absent vision, vibration and platform sway referencing ($-10.708 + -4.472 + -17.417 = 67.403$). The actual mean was 68.000. While multiple regression analysis was not used to analyze the data (due to a violation of a specific assumption required for regression) the percentages of effect provide a good estimate of the influence of specific sensory input. While the influence of the vestibular system can not be assessed using the EquiTest system with normal subjects, the fact that normal subjects do not fall despite a variety of sensory conflicts confirms previous reports that vestibular input is the

dominant arbitrator of postural control (Forssberg and Nashner, 1982).

The small influence of vibration on postural stability, though significant, is not surprising. Vibration primarily affects muscle spindle firing patterns which are only one of many inputs contributing to proprioception. The percentage of effect observed when the platform is sway referenced provides an estimate of the impact of all proprioceptive inputs on postural stability. As expected, the combined influence of joint receptors, muscle spindles, golgi tendon organs and pressure receptors is far greater than that of muscle spindle input alone.

The present data provides compelling evidence that sway referenced visual input has the same effect on postural stability as absent vision does (Table 1). Thus, sway referenced vision neither improves or decreases equilibrium relative to absent vision. This supports the NeuroCom system manufactures' claim that vision is being "nulled out" in the sensory test conditions involving sway referenced vision. It also suggests that the strategy used by the perceptual-motor system to resolve the conflict between inappropriate visual input and other sensory inputs is to ignore the visual input. A simple way to think about the effects of sway referencing vision is that it "blinds" the postural control system to visual inputs. Conversely, a blind individual, free of vestibular impairments, should perform equally as well as a sighted individual experiencing sway referenced vision.

While the negative impact of vibration averaged about 4.5 % across conditions, all sensory test conditions were not equally effected. The difference scores in Table 2 reflect the fact that only sensory test conditions 1-4 were significantly influenced by vibration. The question of why vibration differentially impacts postural equilibrium under different sensory conditions remains to be addressed. Vibration affects both the primary and secondary muscle spindle endings. Primary endings preferentially respond to changes in muscle length while secondary endings are primarily sensitive to velocity changes of the spindle's sensory region. Equilibrium testing using a fixed support surface will result in changes in muscle length at certain velocities in response to subject sway. Thus, both primary and secondary spindle endings will be activated. Vibrating a muscle of changing length will create a conflict between the sensory input associated with the length

change and the vibration induced input. Alternatively, postural sway with a sway referenced support surface will have minimal impact on muscle spindle firing characteristics since subject sway does not alter muscle length. During platform sway referencing the vibration induced input will not interact with input signalling changes in muscle length. Therefore, sensory tests conditions utilizing platform sway referencing offer an opportunity to assess the independent effects of muscle vibration.

Interaction Between Changing Muscle Length and Vibration

The following section offers hypotheses about the possible interaction between changing muscle length and vibration. These hypotheses are based on the trend of the mean difference scores between selected conditions. None of the differences in Table 2 were significant though the difference between conditions 2 and 5 approached significance ($p=.08$).

Sensory condition 2 provides the combination of inputs during which vibration is predicted to have the greatest effect on postural stability. Sensory condition 5 provides a sensory input combination on which vibration is predicted to have minimal impact on equilibrium. In both conditions 2 and 5 vision is absent. What is different is that in condition 2 the triceps sura changes length during postural sway. As hypothesized, the influence of vibration is increased relative to condition 5 (Table 2). This finding supports the idea of an interaction between vibration and changing muscle length. The minimal impact of vibration in condition 5 suggests that proprioceptive input associated with subject sway is effectively "nulled out" when the platform is sway referenced.

Given the effects of vision sway referencing are nearly identical to those of eye closure (Table 1), and that platform sway referencing "nulls out" proprioceptive input, the results from sensory test conditions 5 and 6 should be similarly effected by vibration. While the difference score in condition 6 is 3 percent greater than condition 5, these conditions were the only conditions not significantly effected by vibration (Table 2). The difference scores for conditions 5 and 6 also support the idea that applying vibration to a muscle of static length will have limited impact. Sensory test condition 3 involves sway referenced vision with subject sway resulting in muscle length changes. Thus, conditions 2

and 3 can be considered equivalent and the difference scores reflect this equivalence.

The evidence presented up to now suggests that vibration strongly contributes to postural instability when imposed on muscles of changing length. The effect of applying vibration in sensory test condition 4 presents a paradox. Since condition 4 involves platform sway referencing, applying vibration would not be predicted to have a significant impact on postural equilibrium. However, the data do not support such a conclusion. Although the platform is not sway referenced in condition 1, it can be argued that there are only small changes in muscle length due to the lack of subject sway, therefore sensory test conditions 1 and 4 can be considered equivalent. Since both of these conditions involve normal vision it appears likely that vision interacts with vibration to decrease postural stability despite the lack of changes in muscle length. While it is recognized that this final section is highly speculative it does provide a starting point for future investigations.

CONCLUSIONS

The results of the present study support the following conclusions:

- 1) The effects of specific sensory input manipulations on postural stability can be fairly accurately quantified.
- 2) The NeuroCom postural stability testing system effectively "nulls out" both vision and proprioceptive inputs associated with postural sway.
- 3) The negative impact of triceps sura vibration on postural stability is greatest when imposed during sensory test conditions allowing changes in muscle length.

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